FORCED CONVECTION FROM A CYLINDER IN CROSS FLOW

إعداد

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المرحلة الثالثة

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OBJECT:

To study the variation of average Nuesselt number with Reynolds number.

APPARATUS:

The apparatus of perspex working section, 12.5cm X 12.5cm through which air may be drawn by an electric driven centrifugal fan having its inlet connected to the working section. An element consisting of a rod of pure.' copper, between two extension rods of fabric based plastic-, may be inserted at the center of the working section with its axis at right angles to the direction of air flow. Arrangements are made for heating this copper element by inserting it in a cylindrical electric heater located out of and under the working section to the left. The heater can raise the temperature of the element to a maximum value of about 80° C By replacing the element after heating in the working section and recording its rate of cooling as indicated by a thermocouple with a hot junction fitted at the center .of the element, a semi-logarithmic plot of rate of cooling, can be drawn. This curve permits, the direct calculation of the heat transfer-coefficient between the element and the air flowing passed it as the' thermal capacity and surface area of the copper element are known. The. element temperature is indicated by a thermocouples connected to a potentiometer. The potentiometer records the temperature difference between the hot junction embedded in the element and room temperature. The thermocouple in the element and at the air inlet are of copper and constantan, within the range off 0°-50° C temperature difference, the temperature characteristic of the thermocouples is approximately linear and may represented by 1°C=0.041mv. where mv the reading of the potentiometer. The initial temperature of the air is indicated by a mercury glass thermometer at the air inlet.

Air enters the. apparatus through a bell mouth. After the working section transition piece leads to the fan inlet and carries a honey comb flow straightener. Intended to prevent the transmission of swirl from the fan back into the working section. The fan discharges to a graduated throttle valve by means of which air velocity through the apparatus is regulated. Static pressure tapping and a total head tube are provided so that the velocity head may be recorded by means of the manometer.

THEORETICAL BACKGROUND:

The following assumptions are made:

a) The velocity head upstream of the working section is in fact equal to the pressure drop between atmospheric and the upstream static pressure tapping. Once this has been established the depression at the static tapping may be used as a measure of H.
b) The whole of the heat loss from the cylindrical copper element is transferred to the air flowing passed it.
c) Temperature gradients within the element are negligible, so that the thermocouple embedded at the center gives a true Indication of the effective surface temperature.

A certain amount of heat is conducted from the element into the plastic extension pieces. The extent of this effect has been determined by making comparative test using copper elements with identical diameter but of varying length From these tests the equivalent additional surface area to be added to the real surface area of the copper element in order to include the heat loss from the. plastic extensions has been-calculated. This, means that, in the calculations an. equivalent length have to be used instead off the true length. The equivalent length is found to be 8.4mm more than the true or real length of the copper element.

With the above assumptions it may be shown that (see principles of heat transfer by Kreith, page 110).

$$\frac{T-T_f}{T_i-T_f} = e^{-Aht/mC} \quad (1)$$

Where T is the temperature of the element at any time t; T_f is the air temperature T_i is the element temperature at t=0, A is the surface area of the element, h is the heat transfer coefficient, m is the mass of the element and C is the specific heat of the element. From equation (1):

$$\ln(T - T_f) = \ln(T_i - T_f) - \left(\frac{Aht}{mC}\right) \quad (2)$$

Or

$$log(T - T_f) = log(T_i - T_f) - \left(\frac{Aht}{2.3026mC}\right) \quad (3)$$

equation (3) suggest that a plot of log(T - T_f) against t should yield a straight line of slope M where M is given by:

$$M = \frac{-Aht}{2.3026mC}$$

Since all factors other than h are known, h may be calculated from (4)

Neglecting to compressibility, velocity of air upstream of the element, V, may be calculated by:

$$\rho\frac{V^2}{2} = H \quad (5)$$

where H is the measured velocity head, and ρ is the air density which can be calculated from (6) below:

$$\rho = \frac{P_A}{RT_A} \quad (6)$$

where R is the air gas constant. Note that, the conversion factor .1 cm H_2O=98.1 N/m^2 may be needed.

TEST PROCEDURE:

The apparatus should be set up with heated element at the center of the working section, the manometer should be connected to the total head tube, which should be located in the center upstream position, the opening of the total head tube should be located on the horizontal centerline of the working section and facing upstream. The other leg of the manometer should be connected to the static tapping at the upstream end of the working section. The throttle valve should be closed. To perform the experiment do the following steps;

1) Switch on and standardize the thermocouple potentiometer. Then connect the ends of thermocouple wires to the potentiometer terminals
2) Record the atmospheric temperature and pressure.
3) Start up the fan and open the throttle valve (at the exit of air) to give the desire air flow rate. And record the reading of the manometer.
4) Removed the copper element from the working section and insert it in the electric heater and switched it on. When the temperature of the element reaches a value in the range 60-70°C, corresponding to a thermocouple voltage of 2.4 mv, remove the element from the heater and place it again in the working section.
5) Now set the potentiometer to a value rather lower than that corresponding to the temperature of the element and record the set value, observe the galvanometer needle and when the needle passes through the zero position start a stop watch. Re-set the potentiometer to a lower value and observe the stop watch reading when the galvanometer needle again passes the zero mark record the measured time. Repeat this operation for a series of diminishing potentiometer settings; the resulting information enables a cooling curve to. be plotted, for a particular opening value of the throttle valve.

The above procedure (steps 3,4 and 5) should be repeated for different valve settings. Make use of the following properties of the copper element; diameter=12.47mm, true length 95.02mm, effective length 103.42mm, mass 106.9 g and specific heat = 380 J/kg.K

RQUIRED RESULTS

a) Plot, the cooling curves $\log(T-T_A)$ vs time for at least one Reynolds's number.
b) Plot Nusselt number vs Reynolds number and find the correlating equation.
c) Compare your results with the results available elsewhere (refer to Principles of heat transfer by Kreith, p.457).
d) Discuss your results.

Sample of Calculations

Properties of air at 20° C:

$\rho = 1.204$ (kg/m^3)

$\mu = 1.825 \times 10^{-5}$ (kg/m.s)

$\nu = 1.516 \times 10^{-5}$ (m^2/s)

k = 0.0257 (W/m.k)

for valve 40% open

$$\Delta P = m.r \times \rho g = 1/1000 \times 1000 \times 9.81 = 9.81$$

$$u = \sqrt{\frac{\Delta P}{\rho g}\ x\ 2g} = \frac{9.81}{1.204\ x\ 9.81}\ 2\ x\ 9.81 = 4.0367 \text{ m/s}$$

$$Re = \frac{u\ d}{\nu} = \frac{4.0367 \times 12.47/1000}{1.516\ x\ 10^{-5}} = 3320.34$$

For T = 160° F = 71.11° C , t = 29 sec:

$$\ln\frac{T - T_f}{T_i - T_f} = -\left(\frac{Aht}{mC}\right) \Rightarrow \ln\frac{71.11 - 20}{82.22 - 20} = -\left(\frac{h\ x\ 4.0515\ x\ 10^{-3}\ x\ 29}{0.1069\ x\ 380}\right)$$

$h_1 = 68.0054$ (W/m^2.k)

$$A = \pi\ d\ L = \pi\ x\ \frac{12.47}{1000}\ x\ \frac{103.42}{1000} = 4.0515 \text{ m}^2$$

For T = 140° F = 60° C , t = 63 sec:

$$\ln\frac{T - T_f}{T_i - T_f} = -\left(\frac{Aht}{mC}\right) \Rightarrow \ln\frac{60 - 20}{82.22 - 20} = -\left(\frac{h\ x\ 4.0515\ x\ 10^{-3}\ x\ 63}{0.1069\ x\ 380}\right)$$

$h_2 = 70.3117$ (W/m^2.k)

$$h_{av} = \frac{70.317 + 68.0054}{2} = 69.15855 \mathit{(W/m^2.k)}$$

$$Nu = \frac{h_{av}\ x\ d}{k} = \frac{69.7398\ x\ 12.47/1000}{0.0257} = 33.8387$$

$T_\infty = 20^\circ C$

التاريخ / / ٢٠١

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هاجر

فرح معن ٢٠١١/١١/٢٤

40%

temp. °F	time Sec.	$m.r = \frac{\Delta P}{\rho g}\Big\vert_{water}$ (mm)
$T_i = 180$	0:0	1mm
T = 160	29	
T = 140	63	

55%

$T_i = 180$	0:0	
160	25	3mm
140	53	

65%

$T_i = 180$	0:0	
160	22	5mm
140	45	

75%

$T_i = 180$	0:0	
160	21	8mm
140	43	

$\frac{1}{1000}$

$\Delta P = m.r \times \rho g\Big\vert_{water}$

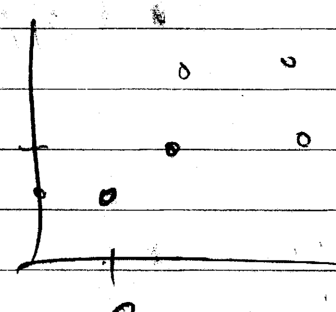
$u = \sqrt{\frac{\Delta P}{\rho g\big\vert_{air}} \times 2g}$

$Re = \frac{\rho . u . d}{\mu}$

$$\boxed{\ln \frac{T - T_\infty}{T_i - T_\infty} = -\frac{hA}{m.c}\, t} \rightarrow h \rightarrow h$$

$h_{av} = \frac{\sum h}{n}$

$Nu = \frac{h_{av} . d}{k_{air}}$

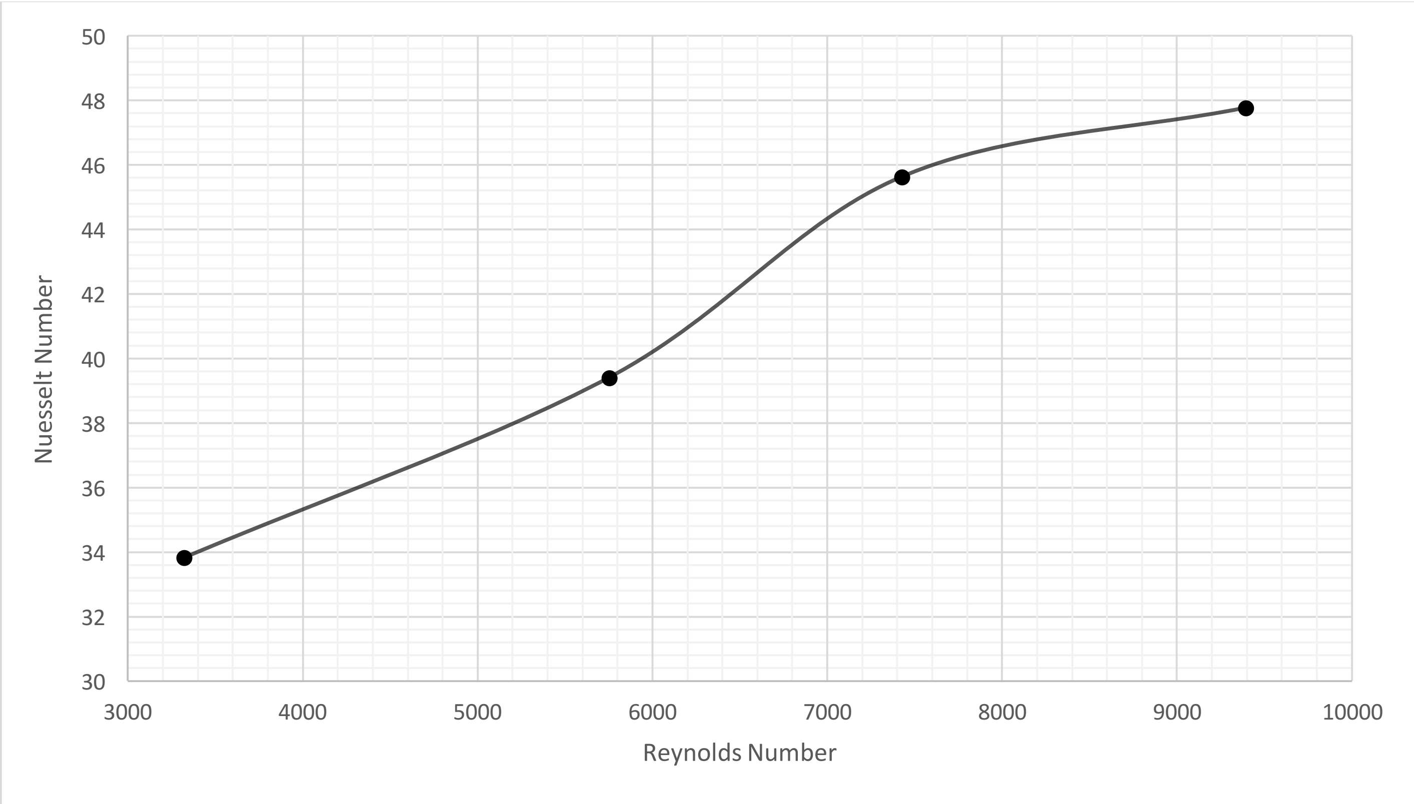


ρ, μ, k air from table at $T_\infty = 20^\circ C$

Table of Results

Valve opening	Temp. °F	Time sec	Manometer reading	Re	Nu
40%	T_i = 180 T = 160 T = 140	0 29 63	1 mm	3320.34	33.83
55%	T_i = 180 T = 160 T = 140	0 25 53	3 mm	5751.03	39.41
65%	T_i = 180 T = 160 T = 140	0 22 45	5 mm	7424.86	45.63
75%	T_i = 180 T = 160 T = 140	0 21 43	8 mm	9391.79	47.77

Re – Nu Diagram



The Correlating Equation:

$$Re \propto Nu$$

DISCUSSION

By measuring the temperature under steady-state conditions we were able to determine the heat transfer coefficients for copper subjected to forced convection. our results indicate that the heat transfer coefficient grows bigger as we open the valve to increase air flow to dissipate more heat from the copper rod, and this is the principle of forced convection

The more air we let in the more heat dissipation will occur decreasing the amount of time required to dissipate the heat from the copper rod and therefore increasing Nuesselt number which is proportional to Reynolds number according to our calculation

Heat is a common phenomenon that occurs everywhere, especially in chemical engineering facilities as a whole. With all of the different applications that heat is involved in, it is obvious cooling is necessary. It is applied to numerous different materials, but the main points of focus are metal and polymer. The graph gained gave an idea of what types of values were to be gained for Nuesselt Numbre and Reynolds number. These values helped in determining copper had a high heat transfer coefficient. Knowing the heat transfer coefficient for any type of material will help in determining how long it can take for a material to cool from the inside out.